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ORIGINAL PAPER

Population structure and regeneration patterns of tree species in climate-sensitive subalpine forests of Indian western Himalaya

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Abstract: The population structure of tree species has been explored in order to elucidate regeneration potential of the subalpine forests of Indian western Himalaya. For this study, the subalpine forest area was divided into three strata, i.e., lower altitude (<3000 m); mid-altitude (3000–3200 m); and high altitude (>3200m). Considering the major compositional attributes, an increase in altitude came with a significant decline in tree density and the total basal area for all the sites. However, no such clear trends were observed for recruits (i.e., seedlings and saplings). Seedling density did not exhibit uniform patterns for sites and altitude strata. In general, overall seedling density was greater at the Pindari site compared to the Lata and Tungnath sites. By comparison, significant variation in seedling density along the altitude strata was recorded for the Tungnath and Pindari sites only. Likewise, sapling density patterns varied across the sites and altitude strata, and significant variation in sapling density along the altitude strata was recorded only for the Lata site. At the Pindari site, the continuous increase in sapling density along with increasing altitude was revealing. The Pindari forests of exhibited expanding population structure. In contrast, greater accumulation of individuals in the sapling class and sharp decline toward both higher tree classes and lower seedling classes was generally apparent for the Lata and Tungnath sites. This indicates that the replacement in tree size classes from sapling stage is not proportional and the population may decline in the long-term. Considerable variation in patterns of forest and dominant species population structure were evident across altitude strata. But in all cases irrespective of sites, we found growth at the high-altitude stratum, in the form of entire forests or dominant species. This trend deserves further investigation to explore its relevance under changing climate scenarios.

Key words: population structure, regeneration, subalpine forest, altitude

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Introduction

Population structure studies are important for understanding the mechanism of species coexistence and long-term ecological processes of natural forests (Miura et al. 2001). They reveal the dominance status of species and development within the community. Population structure and recruitment patterns are influenced by many factors, such as disturbance and competitive interactions between trees (North et al. 2004). The structural characteristics are also used to define niche requirement of species, examine spatial heterogeneity, temporal dynamics of understory vegetation and investigate pattern of regeneration dynamics (Runkl 1991; Long and Smith 1992; Chen et al. 1993; Boungiorno et al. 1994; Chen and Franklin 1995). Similarly, the mechanism determining spatial pattern and maintenance of species richness can be inferred from differences in the spatial distribution of juvenile and adult trees (Hamill and Wright 1986; Hubbel and Foster 1987). As such, the regeneration patterns of species, based on the population structure, can determine the seral stage of the community and infer the potential climax vegetation of a particular area.

Vegetation zones, arrayed on the basis of altitude, are one of the most remarkable gradational patterns of vegetation (Ohsawa 1984). In mountains, the subalpine forests represent a transition between alpine grassland and temperate forest ecosystems. These forests are considered vulnerable to natural variations in climate

and also under high anthropogenic pressure (Kullman 1988; Stevens 2003; Sharma et al. 2009). Because of their distinct biodiversity and sensitivity to climate change and anthropogenic disturbances, these forests have been recognized as worthy of further investigation in Indian western Himalaya (Rawal and Dhar 1997). The current interest in studying the subalpine forests has also been prompted by widespread predictions of future climate change and its impact on altitudinal location of the timberline (Kullman 2001; Holtmeier 2003; Kultti 2004).

Comprehensive studies on compositional attributes of vegetation, including diversity patterns of subalpine forests of western Himalaya have been conducted (Bankoti 1990; Garkoti 1992; Singh et al. 1994; Rawal and Pangtey 1994; Dhar et al. 1997; Hussain et al. 2008; Gairola et al. 2008; 2009). The structure and composition of subalpine forests in Indian western Himalaya are strongly influenced by the types and sizes of disturbances to the forest canopy (Kumar and Ram 2005; Gairola et al. 2008; 2009).

However, efforts to specifically describe the structural properties of subalpine forests to elucidate the regeneration pattern of tree species are largely lacking. Considering this gap, we describe the population structure (demographic profile) of tree species along the altitudinal gradients in subalpine forests of Indian western Himalaya. These forests have great ecological importance for they are home to a large number of threatened and charismatic species of flora and fauna, and at the same time sensitive to climate change. An attempt has been made to interpret certain trends and major aspects of regeneration on the basis of the existing state of seedling, sapling, and young tree populations. The specific objective of this study was to investigate the population structure of forest tree species along altitudinal gradient, and to provide some implications for the regeneration of dominant species in this ecological sensitive zone in Indian western Himalaya.

Materials and methods

Study locality

The present study was conducted in three sites: Tungnath (30°14′ N; 79°13′ E) and Lata (30°29′ N; 79°44′ N) in the Garhwal region; and Pindari (30°10’ N; 79°52′ E) in the Kumaun region of western Himalaya, covering an altitude of 2800 m to 3600 m asl. The altitudinal range covered in the present study represents a transition from closed-canopy temperate forests to open-canopy subalpine forests. The climate of the study area is characterized by short cool summers and long severe winters. Anthropogenic disturbance in these sites mainly occurs in the form of grazing (including migratory grazing). However, lopping of trees for fuel wood and fodder, removal of litter, and tourist activities during summer season are other factors.

Vegetation survey and data analysis

After general reconnaissance, two vertical belt transects were laid in each site along the altitudinal gradient. Each transect was stratified into three altitude zones or strata (viz. <3000 m; 3000 – 3200 m; >3200 m). In each stratum, three 50 x 50 m plots were laid systematically, hence a total of 18 plots were established. In each 50 m × 50 m plot, five (10 m × 10 m) quadrats were laid randomly for enumeration of tree species. Each individual 10 x 10 m quadrat was further subdivided into 2 m × 2 m subquadrats for enumeration of seedlings and saplings. In the case of trees, CBH (circumference at breast height, 1.37 m from the ground) was measured and individuals were classified as trees: > 30 cm; sapling: 11 – 30 cm; seedlings: <11 cm CBH. All of the species and the number of individuals in each quadrat were recorded. The basic CBH information of individual tree generated from each quadrat was used for development of population structures. The density distribution (d-d) in size (CBH) classes was employed to develop the population structure of tree species. The individuals in each tree species were grouped into seven arbitrary CBH classes (A: <10; B: 11–30; C: 31–60; D: 61–90; E: 91–120; F: >121–150; G: >150 cm).The total number of individuals belonging to an individual class was calculated for each species in representative strata/plots. Class A and B represent seedlings and saplings, respectively, and other classes (C-G) represent individual trees. Relative density in a particular size class was calculated as a percentage of the total number of individuals in all size classes. The regeneration status of dominant trees was assessed based on proportional distribution of density of individuals in each seedling, sapling and adult tree class.

Results

The population structure of tree species—in terms of proportion of seedlings, saplings, and adults—varied in the three study sites along the altitudinal gradient. At the Pindari site, the population structure exhibited more or less similar trends across different altitudinal strata. High accumulation of seedlings and saplings and rapid decline of individuals in tree-size class were also characteristic of this site (Fig. 1a). At the Lata site, two trends emerged: a characteristic bulge at the sapling stage and a sharp decline toward the seedling- and tree-size classes (Fig. 1b). The structure of subalpine forests at the Tungnath site showed variations among the altitudinal strata (Fig. 1c). The higher proportion of individuals in the sapling stage at <3000 m and 3000–3200 m and seedling stage at >3200 m a.s.l. was revealing.

The distribution of seedlings, saplings, and adults along the altitudinal gradient also showed variations among dominant species. At the Pindari site, at lower altitude strata (<3000 m), the dominant species showed higher number of individuals in the seedling and sapling stages and decreasing numbers in the higher tree-size classes (Fig. 2a). The population structure at the mid-altitude strata (3000–3200 m), showed a greater proportion of individuals in the seedling and sapling classes and a sharp decline toward the tree-size classes. At this stratum, all dominant species, barring *Acer caesium*, showed a higher accumulation of individuals in the seedling stage (Fig. 2b). At higher altitude strata, size-class distribution of the species showed a considerably higher percentage of individuals in the seedling and sapling

stages and a sharp decline in the adult stage. The entire stand structure exhibited a high percentage of individuals in the seedling and sapling stages and a sharp decline the tree-size classes (Fig. 2c).

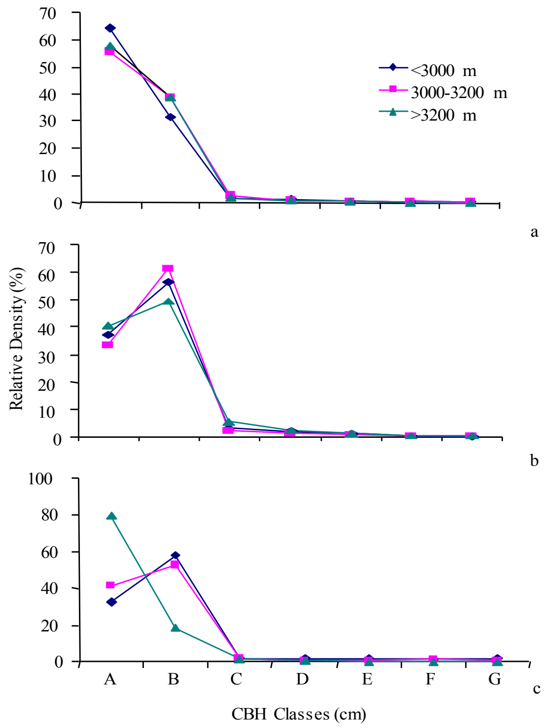

Fig. 1: Population structure of forests across altitudinal strata in different site (a—Pindari, b—lata, c—Tungnath)

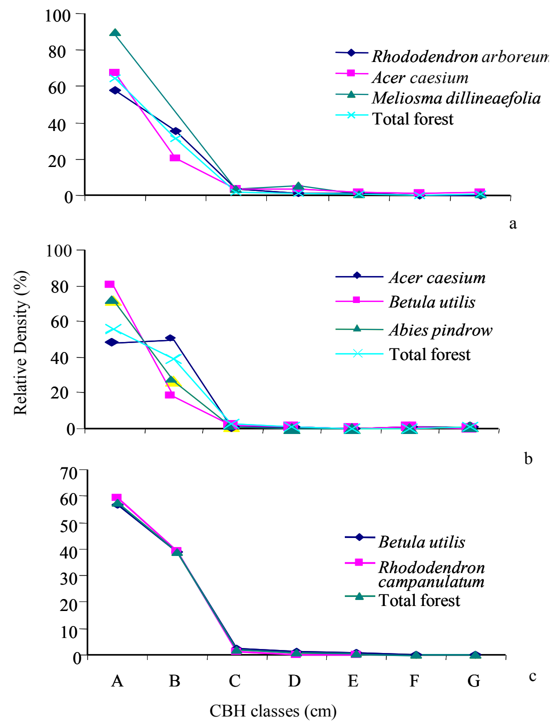

Fig. 2: Population structure of dominant tree species and entire forest stand in Pindari. a <3000 m, b. 3000-3200 m, c. >3200 m

At the Lata site, a characteristic bulge at the sapling stage and a sharp decline toward the seedling and tree-size classes was apparent. At lower altitude strata (<3000 m), dominant species *Pinus wallichiana* and *Populus ciliata* exhibited similarity with the overall forest structure, while *A. pindrow* did not follow the same trend (Fig. 3a). At mid-altitude strata (3000–3200 m) *A. pindrow* showed the most promising structure with a relatively high proportion of seedlings followed by saplings and adults (Fig. 3b). This pattern did not match with other dominants and overall forest structure. At higher altitude strata (>3200 m), *B. utilis* and *A. pindrow* exhibited greater numbers of individuals in the sapling stage and a gradual decline for seedlings and a sharp decline toward adults. *R. campanulatum* was present in tree-size class only and recruits (seedling and saplings) were altogether absent (Fig. 3c).

At the lower altitude strata (<3000m) of Tungnath, other dominants were having large number of saplings, except for *A. pindrow*, and very few seedlings and adult tree individuals were found (Fig. 4a). In the mid-altitude strata (3000–3200 m), *A. pindrow* had individuals in sapling and higher size classes. *A. caesium* with accumulation of sapling individuals showed marked similarity with the population structure of the entire forest (Fig. 4b). At higher altitude strata, *Q. semecarpifolia*, and *R. barbatum* showed distribution of individuals in the seedling, sapling, and tree-size classes but in case of *A. pindrow,* only individual saplings were present (Fig. 4c).

Proportionate distribution of individuals in the seedling, sapling, and tree, layers along altitudinal gradients showed different trends across the study sites. In Pindari, the distribution of seedlings, saplings and trees, followed a more or less similar pattern. Seedling density was highest followed by saplings and trees. Relatively higher sapling density was revealed at Lata followed by seedlings and trees. Similar trends were observed for <3000m and 3000–3200 m altitude strata at Tungnath. However, at >3200 m altitude strata considerably higher density of seedlings was recorded (Fig. 5).

Considering the compositional attributes, while all sites showed continuous decline in tree density with increasing altitude, the variation in tree density was significant at Tungnath ($F = 3.61$, $p < 0.05$) and Lata ($F=8.71$, $p < 0.001$) only. Total basal area decreased significantly in all the sites as altitude increased (Tungnath: $F = 19.02$, $p < 0.01$; Lata: $F = 16.81$, $p < 0.001$; Pindari: $F = 7.29$, $p < 0.01$). Seedling density did not exhibit uniform patterns for sites and altitude strata. In general, overall seedling density was greater at Pindari compared to Lata and Tungnath. The highest seedling density (10135 indi·ha^{1}) was recorded at <3000 m altitude in Pindari and the lowest (1867 indi.ha^{1}) at >3200 m in Lata. S significant variation in seedling density along altitude was only recorded for Tungnath ($F = 12.19$, $p < 0.001$) and Pindari ($F = 4.25$, $p < 0.01$). Likewise, sapling density patterns varied across sites and altitude strata. Sapling density was highest (8333 indi.ha^{1}) at 3000–3200 m altitude in Lata and lowest (2200 indi.ha^{1}) at >3200 m altitude in Tungnath. Significant variation in sapling density along altitude was recorded only for

Lata; in case of Pindari, however, sapling density increases with altitude (Table 1).

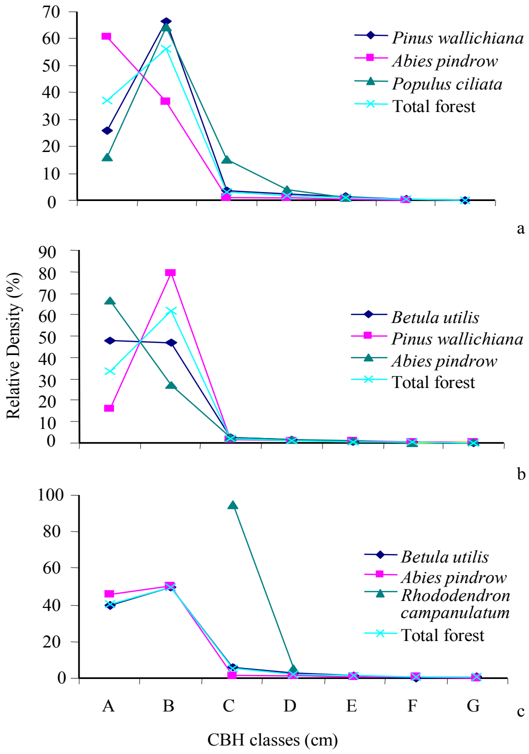

Fig. 3: Population structure of dominant tree species and entire forest stand in Lata. a <3000 m, b. 3000-3200 m, c. >3200 m

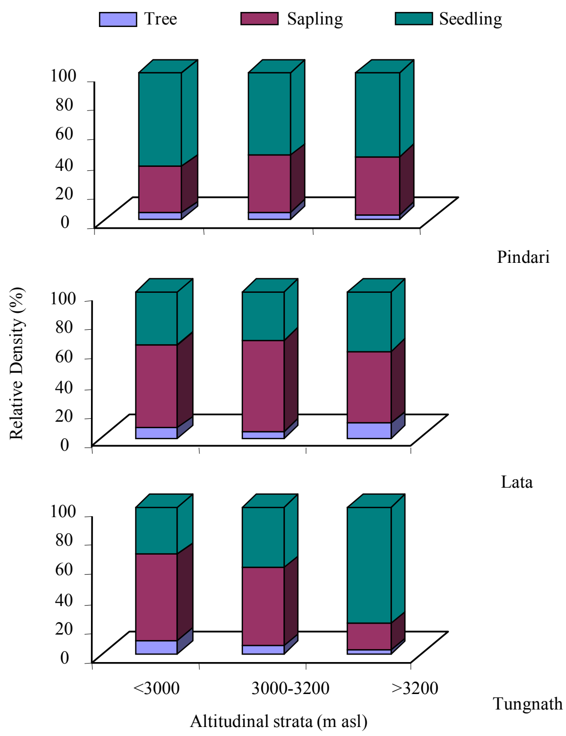

Fig. 5: Proportionate distribution of tree, sapling and seedling along altitudinal strata in different sites.

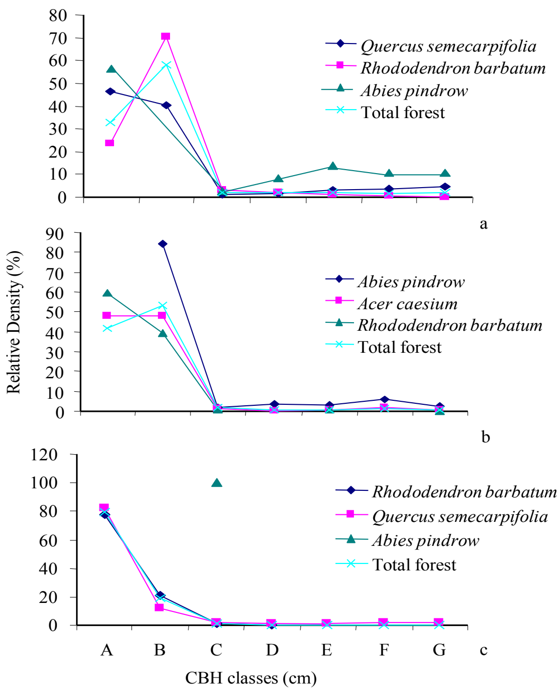

Fig.4: Population structure of dominant tree species and entire forest stand in Tungnth. a <3000 m, b. 3000-3200 m, c. >3200 m

Table 1: Summary of forest structure across sites and along altitude

Site	Tree density (Indi.ha^{1})	TBA (m^{2} ha^{1})	Seedling density (Indi.ha^{1})	Sapling density (Indi.ha^{1})
Tungnath				
<3000 m	634	69.84	2267	4067
3000-3200 m	384	35.83	2867	3667
>3200 m	243	8.94	9333	2200
LSD (0.05)	249.10	21.15	3416.13	4951.60
F ratio	3.61*	19.02**	12.19***	0.358
Lata				
<3000 m	843	35.33	4467	7017
3000-3200 m	636	30.16	4533	8333
>3200 m	453	15.29	1867	2267
LSD (0.05)	199.32	7.76	3697.28	2294.03
F ratio	8.711***	16.81***	1.538	17.76***
Pindari				
<3000 m	646	37.16	10135	4934
3000-3200 m	580	31.09	7666	5267
>3200 m	557	16.75	9866	6667
LSD (0.05)	244.50	13.75	1977.98	3619.98
F ratio	0.279	7.29**	4.25**	0.587

Significance levels *p <0.05; **p <0.01; ***p <0.001 respectively

Discussion

The distribution pattern of a plant species indicates its adaptability to various environments (Wang et al. 2004). The character of forest communities mainly depends on the ecological characteristics of sites, species diversity, and regeneration status of species. A greater accumulation of individuals in the sapling stage and a sharp decline toward both higher tree classes and lower seedling classes result hill-shaped curves in the Lata and Tungnath sites. This type of structure indicates that the replacement in tree size classes from sapling stage is not proportional. It also suggests that if the current state of seedling recruitment does not improve, the population may decline in the long term. On the contrary, forest structure in the Pindari site is expanding in nature with more individuals in the seedling and sapling stages, followed by a decline in the tree size classes. Population structure of the dominant associate gives an impression of maintenance mechanism of populations of such species.

The presence of a sufficient number of seedling, sapling, and young trees in a given population indicate successful regeneration (Saxena and Singh 1984). The importance of individual-level population structure assumes higher importance when the environmental conditions (e.g., eco-physiology) at subalpine forests (SAF) do not permit most species to follow the normal life cycles. At the Lata and Tungnath sites, the hill-shape structure of the dominant species suggests their improper conversion into trees and relatively poor density of seedlings. This trend would indicate possible difficulties in the long-term persistence of such species.

Among dominant species at the Lata site, several enjoy long-term persistence, including: *Q. semecarpifolia* and *A. pindrow* at lower elevations, *R. barbatum* and *A. caesium* at mid elevation, and *R. barbatum* and *Q semecrpifolia* at higher elevations, all , with more or less expanding population structures.At the Tungnath site, population structures indicate that *A. pindrow* at low and mid altitudes, and *Q. semecarpifolia* at higher altitude strata would continue to grow.

The immediate co-dominant species in most sites also exhibited progressive population structures. These features suggest the broad composition of the SAF in these sites will persist in the near future. The profiles of relatively less prominent tree species also warrant attention. For example, *Rhododendron barbatum*, *Salix daphnoides*, *Lyonia ovalifolia*, *Ilex dipyrena*, *Euonymus fimbriatus* and *A. pindrow* in the <3000 m strata of the Pindari site were represented only in the tree layer, suggesting that these species have not reproduced in the past nor in the present, making their long-term persistence doubtful. Kräuchi et al. (2000) also suggested that the lack of sufficient regeneration is a major problem of mountain forests. Previous studies on subalpine forests have also reported poor seedling recruitment in the understories of old-growth forests (Coates 2002; Mori and Takeda 2004).

In contrast, *Sorbus foliolosa* and *Acer villosum,* with individuals only in the seedling and sapling stages indicate these species are relatively new to these sites and it would be interesting to see if such species succeed in attaining tree size classes in future. If it does happen, it might change the forest structure. Interestingly, in the high-altitude strata of the Tungnath site, *A. pindrow* with individuals in the young tree size suggests possibilities of this species succeeding in future as the species not only dominates the low-mid altitude strata but also enjoys expanding population structure.

In the mountains, gradual changes in vegetation structure and composition are expected as a consequence of changing environmental conditions along the increasing elevation. Also, anthropogenic activities cause changes in structural attributes (Gairola et al. 2009). The unusually low density of sapling at >3200 m altitude strata at Tungnath is indicative of problems in conversion of seedlings to saplings. Although the exact reasons for this unusual structure are not known, this may be a reflection of higher seedling mortality, caused by trampling by grazing cattle and other unfavourable (stressful) microclimatic conditions.

At the upper limit of the forests, often low temperatures and the short growing season inhibit growth and development of trees (Block and Treter 2001; Wang et al. 2004; Zhang 2004). Also, the low seedling density at the mid-altitude strata (3000m-3200m) may be attributed to low light intensity on the forest floor due to dense overhead canopy (Barik et al. 1992; Tripathi 2002). In the case of dominant species, inadequate regeneration of the constituent species is a general phenomenon in Indian forests because of grazing, fire, extraction of timber and fuelwood, and cultivation (Shankar et al. 1998, 2001).

In some of the study sites, higher accumulation of seedlings at high altitude (>3200 m) would indicate that fluctuations in climate might play an important role in synchronizing these patterns. The response of tree seedlings to changing climate has yet to be investigated, but reports from the alpine areas of western Himalaya are indicative of changes in snow patterns and temperatures, which are affecting the distribution and phenology of some plant species (Nautiyal et al. 2004; Chaturvedi et al. 2007). Elsewhere, researchers have highlighted that increasing global temperatures linked to greenhouse gas emissions may alter tree growth rates, recruitment and mortality, thereby creating new assemblages of trees (Clark et al. 2003; Laurance et al. 2004; Clark et al. 2005). Hence, the structure of subalpine forests and its relationship with tree regeneration needs further research so as to modulate the timberline response to climatic variability. Change in species composition (e.g., Walther et al. 2005) and increased young tree establishment near the treeline have been reported elsewhere (Korner 2003).

The present study on population structure and demographic profiles of dominant canopy tree species would help understanding the status of regeneration of species, and possible future compositional trends in climate-sensitive subalpine forests of western Himalaya.

Conclusion

This study revealed significant variations in the population structure of the subalpine forests across the three sites and altitude strata. Likewise, the dominant species often showed heterogene-

ity in patterns. Following the traditional patterns of forest population structure, the target forests at the Pindari site are expanding. Broadly, this site does not have immediate threat of change in forest structure. At the other two sites, Lata and Tungnath, if the current trends of sapling to tree conversion persist, the subalpine forests might exhibit considerable change in the future. Among dominants at these sites—*Q. semecarpifolia* and *A. pindrow* at lower altitude, *R. barbatum* and *A. caesium* atmid altitude, and *R. barbatum* and *Q. semecrpifolia* at the highaltitude stratum of Lata and *A. pindrow* at low and mid altitude and *Q. semecarpifolia* at high altitude stratum of Tungnath—are showing better potential for long-term persistence. Across altitude strata, irrespective of sites, the high-altitude stratum with more or less expanding populations (i.e., entire forest or dominant species) suggests the possibility of future expansion. This trend deserves further investigation to explore its relevance with the patterns of vegetation under changing climate.

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